NASA Support for the Future Communications Study

FCS Technology Evaluation Process and Interim Results

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Glen Dyer
ITT – Advanced Engineering & Sciences

Briefing Outline

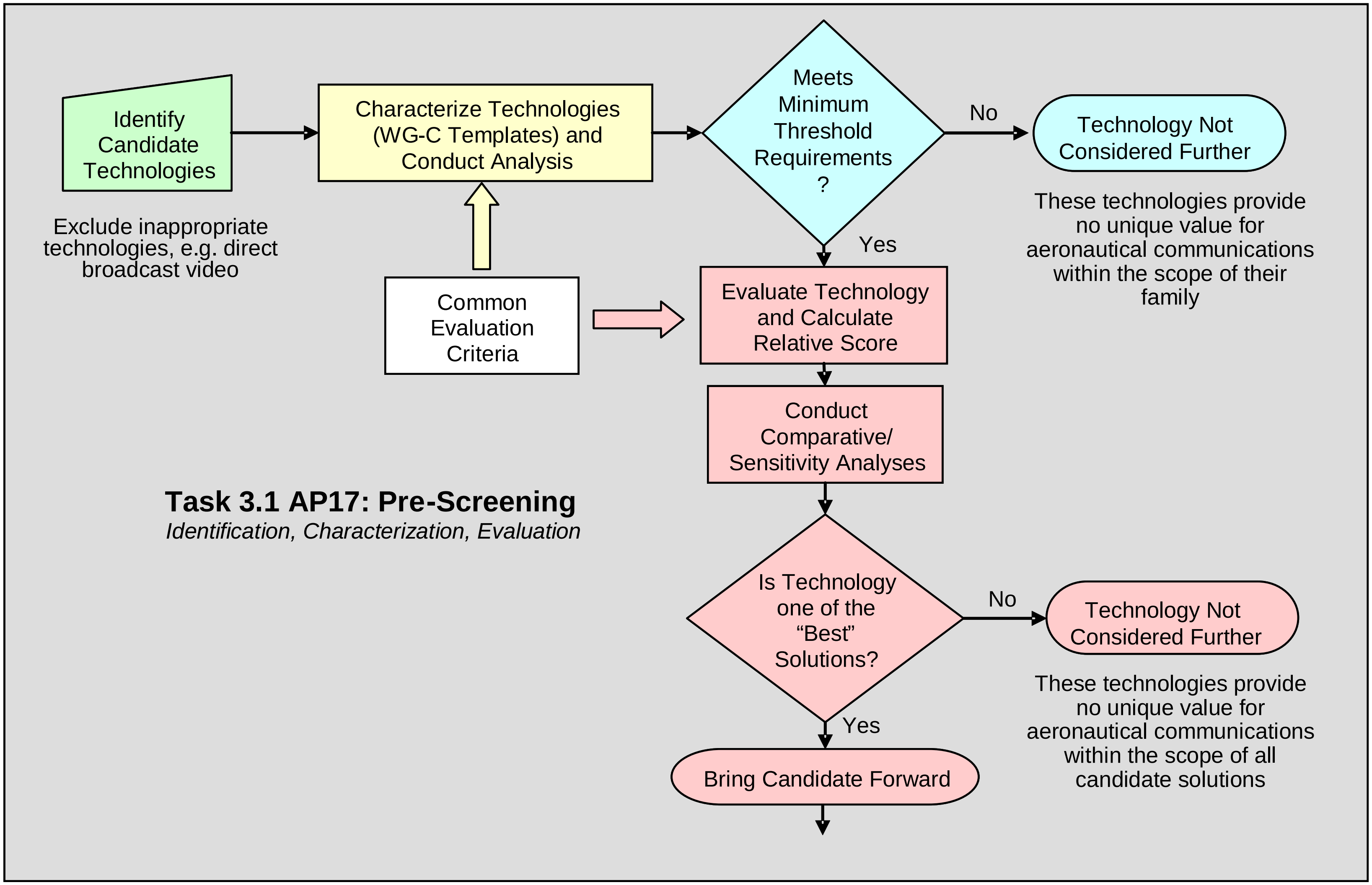
- Background & Previous Work
- Modified Evaluation Process
- Example Application
- Concluding Remarks

Background & Previous Work

Background

- The technology assessment team has been charged to "investigate new terrestrial and satellite-based technologies"
  - Presume that "new" means "new to aviation", as there are pressing spectrum requirements in some regions (notably core Europe, but also in dense US airspace) that predicate urgency
    - Time frame to standardization in aviation is long
    - Further, there is a distinct desire to leverage COTS solutions, or at least realize some efficiency by commonality with other standards bodies
- The technologies that are recommended must:
  - Meet the needs of aviation (as identified in the COCR and ICAO consensus documents)
  - Be technically proven
  - Be consistent with the requirements for safety
  - Be cost beneficial
  - Promote global harmonization

Background: Original Screening Process (Completed 2004)



Background: Technology Inventory

•**Listing** of technologies to be evaluated. The grouping by families was selected for similarity of user requirements. No ranking is to be implied.

Technology Family	Candidates
Cellular Telephony Derivatives	TDMA (IS-136), CDMA (IS-95A), CDMAone (IS-95B), CDMA2000 1xRTT, W-CDMA (US)/UMTS FDD (Europe), TD-CDMA (US)/UMTS TDD (Europe), CDMA2000 3x, CDMA2000 1xEV, GSM/GPRS/EDGE, TD-SCDMA, DECT
IEEE 802 Wireless Derivatives	IEEE 802.11, IEEE 802.15, IEEE 802.16, IEEE 802.20, ETSI HIPERPAN, ETSI HIPERLAN, ETSI HIPERMAN
Public Safety and Specialized Mobile Radio	APCO P25 Phase 1, APCO P25 Phase 2, TETRA Release 1, TETRAPOL, IDRA, IDEN, EDACS, APCO P34, TETRA Release 2 (TAPS), TETRA Release 2 (TEDS), Project MESA
Satellite and Other Over Horizon Communication	SDLS, Connexion by Boeing, Aero B-GAN, Iridium, GlobalStar, Thuraya, Integrated Global Surveillance and Guidance System (IGSAGS), HF Data Link, Special Use Satellite System
Custom Narrowband VHF Solutions	VDL Mode 2, VDL Mode 3, VDL Mode 3 w/SAIC, VDL Mode E, VDL Mode 4, E-TDMA
Custom Broadband	ADL, Flash-OFDM, UAT, Mode-S, B-VHF (MC-CDMA), E-TDMA, LDL
Military	Link 16, SINCGARS, EPLRS, HAVEQUICK, JTRS
Other	APC Phone (Airphone, AirCell, SkyWay)

Background: Original Pre-Screening Recommendations

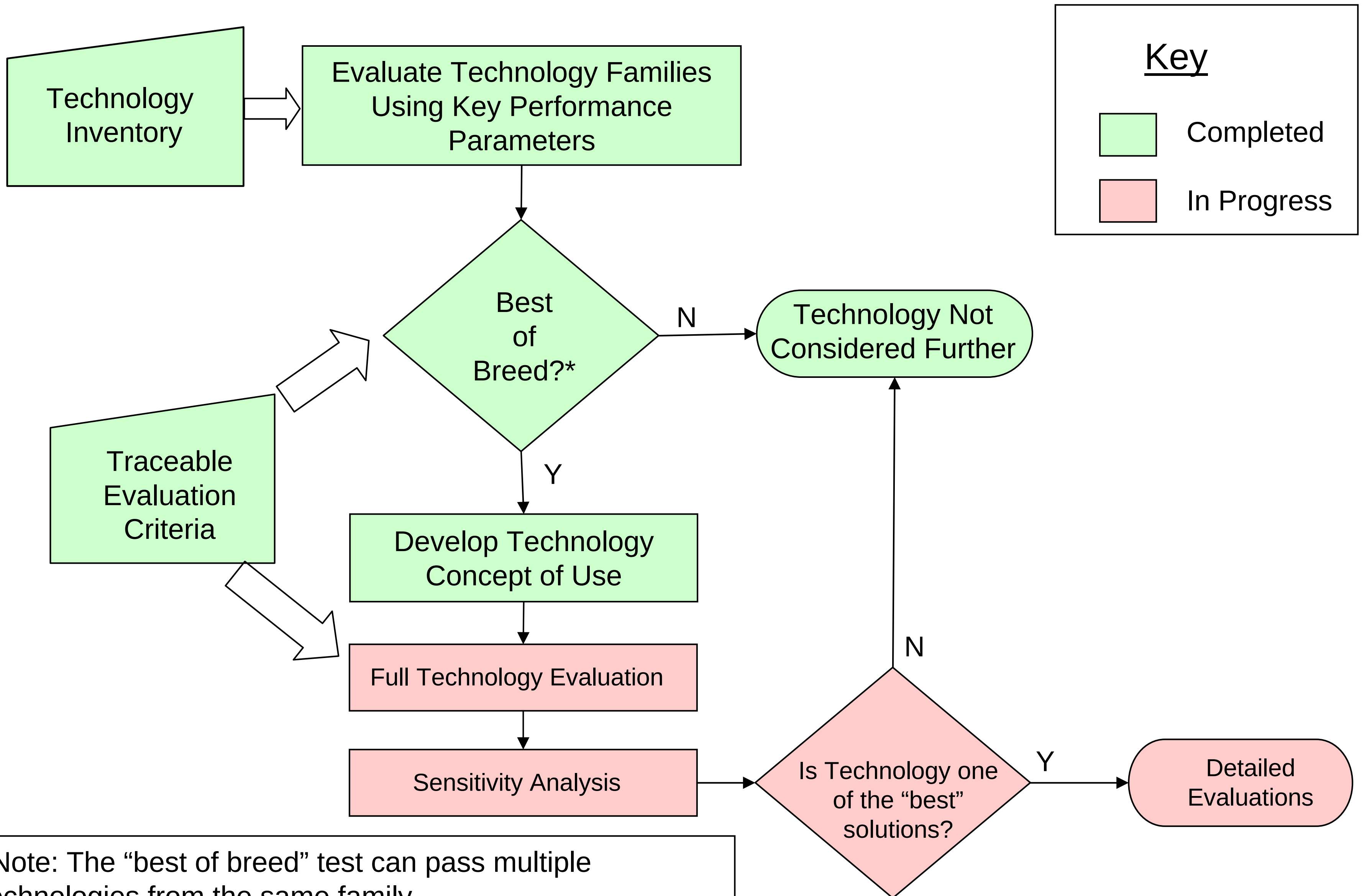
- Technologies applicable in enroute, terminal and surface
  - Primary:
    - B-VHF in DME Band (960 – 1024 MHz)
    - VDL3/E in VHF Band
    - VDL-3 in DME Band (LDL)
    - P34 in DME Band
  - Secondary
    - WCDMA in DME Band
- Technologies applicable to specific airspace domains
  - Oceanic
    - INMARSAT-4 (Aero BGAN) in AMS(R)S Band
    - Iridium in AMS(R)S Band
  - Surface
    - IEEE 802.16 in Extended MLS Band (5091-5150 MHz)

Background: New Focus on Data-Link

- Stakeholder feedback to the original technology screening
  - Focus on solutions for data-link (voice to remain as provisioned)
  - Show direct relationship between evaluation criteria and requirements document (COCR)
  - Re-visit prescreening decisions
- In the original pre-screening, both contractor teams followed an identical process, and the recommended technologies were nearly identical
- For the second technology screening, different approaches are being taken by each team
  - Results of each screening will be checked against the other
  - Differences will need to be justified
  - The greater the intersection of recommended technologies, the greater the confidence in the process/results

Modified Evaluation Process

Modified Evaluation Process



*Note: The “best of breed” test can pass multiple technologies from the same family

Using Key Performance Requirements to Identify Best of Breed

- It can be noted that the technologies that have been identified are grouped into families
  - Families exhibit many similarities
    - Technology has evolved to meet common user requirements
    - Technologies have similar services offered
    - Technologies have similar reference and physical architectures
  - Selecting the "best of breed" from a candidate technology family allows detailed evaluations of a manageable number of technologies
    - If the filter is appropriately chosen, then the candidates brought forward are both the "best of breed" in the technology family and they are those that are most applicable to the needs of aviation
- Selected filter is the derived data loading requirements, the technology communications range and ability to use protected spectrum
  - Clearly, most technologies could be "made to work", by using multiple radios, or a more dense network of radio sites
  - However, if a member of a technology family does not require these (costly) workarounds, it seems very appropriate to focus evaluations on this member of the set
  - A technology that inherently relies on unprotected spectrum [i.e., not AM(R)S or AMS(R)S] will be eliminated

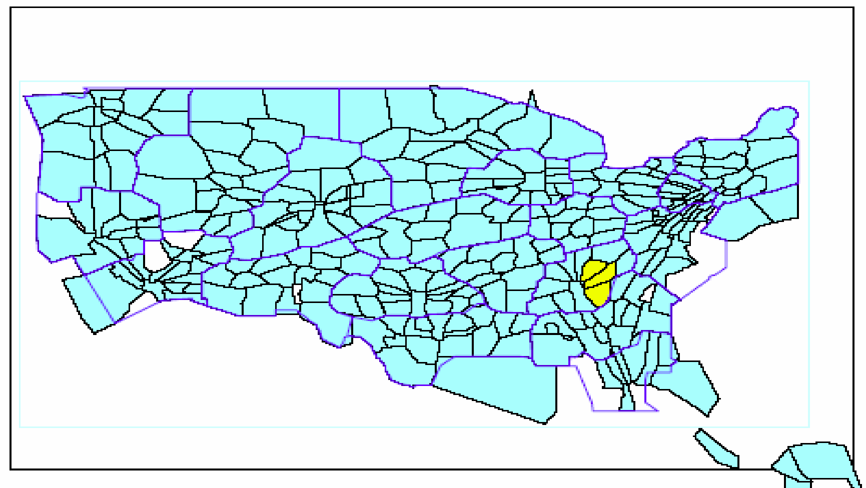
Data Rate Required is in Context to ALL Other Performance Requirements

- The COCR loading requirements consider ALL of the technical evaluation criteria in developing the required data rate
  - ***Data rate*** *required* is for
    - the *maximum* ***number of users***,
    - while provisioning the *required* ***QoS*** (implemented as differing priority queues in the model)
    - while *meeting the* ***latency*** *requirements*
- Technology evaluation that leverages the methodology used in the COCR would require knowledge of
  - Technology coverage volume (affects number of users and hence data rate)
    - Use this to scale data rate required
  - Technology data rate provisioned
    - Compare against required
  - Implicit assumption – technology supports queuing and required number of users (verify and use as gate)

Defining the Measures - Required Data Rate

PHASE 1		APT SV		TMA SV		ENR SV			ORP SV	
		HD	LD	HD	LD	HD EU	HD US	LD	HD	LD
Separate ATS	UL	4.0	1.2	2.3	2.2	1.2	1.5	1.2	0.3	0.3
	DL	4.3	1.9	4.1	3.9	3.7	4.9	3.7	2.7	2.2
	UL&DL	7.4	2.0	5.3	5.0	4.1	5.6	4.1	2.8	2.2
Separate AOC	UL	15.6	2.7	0.3	0.3	8.6	11.9	8.6	3.3	2.8
	DL	3.5	0.7	0.8	0.8	0.8	1.3	0.8	0.4	0.3
	UL&DL	19.9	2.9	0.8	0.8	9.1	13.8	9.1	3.3	2.8
Combined ATS&AOC	UL	18.4	2.9	2.3	2.2	9.0	12.7	8.9	3.3	2.8
	DL	6.7	2.0	4.3	4.1	3.8	5.2	3.8	2.7	2.2
	UL&DL	25.5	3.3	5.6	5.3	11.4	17.7	11.3	4.5	3.4

Table 8-3: Air/Ground Capacity Requirements (kbps) – Phase 1



NAS En-Route "Super Sector"

PHASE 2		APT SV		TMA SV		ENR SV			ORP SV		AOA
		HD	LD	HD	LD	HD EU	HD US	LD	HD	LD	
Separate ATS	UL	12.8	7.1	22.0	22.2	20.9	22.4	21.0	19.8	19.6	7.1
	DL	11.3	5.2	10.3	10.7	9.8	13.5	10.5	8.9	8.7	13.3
	UL&DL	19.6	7.3	24.5	25.1	23.5	27.0	24.0	20.3	19.9	13.6
Separate AOC	UL	113.0	14.1	0.3	0.2	52.4	96.1	64.1	24.0	18.2	56.2
	DL	6.7	1.2	2.4	2.2	1.4	2.7	1.8	0.6	0.4	1.1
	UL&DL	131.2	14.1	2.6	2.3	58.6	106.9	72.6	24.4	18.2	62.8
Combined ATS&AOC	UL	120.0	24.6	22.0	22.2	119.1	168.3	134.8	82.1	62.8	76.7
	DL	13.4	5.4	11.1	11.8	10.2	13.9	10.9	9.0	8.8	13.4
	UL&DL	144.3	24.8	25.2	25.8	119.4	168.9	135.2	82.2	62.9	80.5

Table 8-4: Air/Ground Capacity Requirements (kbps) – Phase 2

- COCR A/G Capacity requirements shown
  - Required data rates range between 0.3 kbps and 168.9 kbps
  - Maximum is for the NAS 2030 "Super Sector" shown on the map
- COCR also provides "per aircraft" data rates
  - Required rate does not scale as a multiplicative factor

Extending COCR Data Rate Requirements

- In general, a technology can be evaluated as
  - “Sector Based” – this is the concept that is detailed in the COCR, with larger future sectors being accounted for, but the volume of coverage is still smaller than technology coverage constraints
  - “Area Based” – in this concept, a regular grid of ground stations is deployed, with minimal overlap of coverage (except for required redundancy for availability concerns)
    - Coverage area is bigger than sectors, and crosses sector boundaries
    - Almost all satellite coverage areas fall into this latter category
  - There are some technologies that must be evaluated on a “per aircraft” basis
    - In general, these are “circuit based” technologies. Iridium is an example.
- COCR provides data rate requirements for specific service volume size (sector based) and for individual users
  - COCR provides a sound engineering process for deriving the required capacity for any arbitrary volume (area based)

Concept of Use

- Fundamental tenet – When assessing a technology, a *concept of use* must be defined.
  - The concept of use can be defined as a mapping of a technology into a system. It provides the basic description of how the required ATS & AOC services (functions) would be provisioned
  - Technology capacities and performance are evaluated in accord with the operational environment for the given concept of use
- Elements of a “concept of use”
  - Services Appropriate for Aeronautical Communications
    - Maps technology services into required aeronautical services
  - Integration of the Candidate’s Architecture for Aeronautical Communications
    - Describes technology architecture for both the service provider and the aircraft
      - Includes ground infrastructure, frequencies used, coverage volumes, number of ground sites (satellites) required – in other words, the *system* that provisions communications

Suggested Process – Full Technology Evaluation

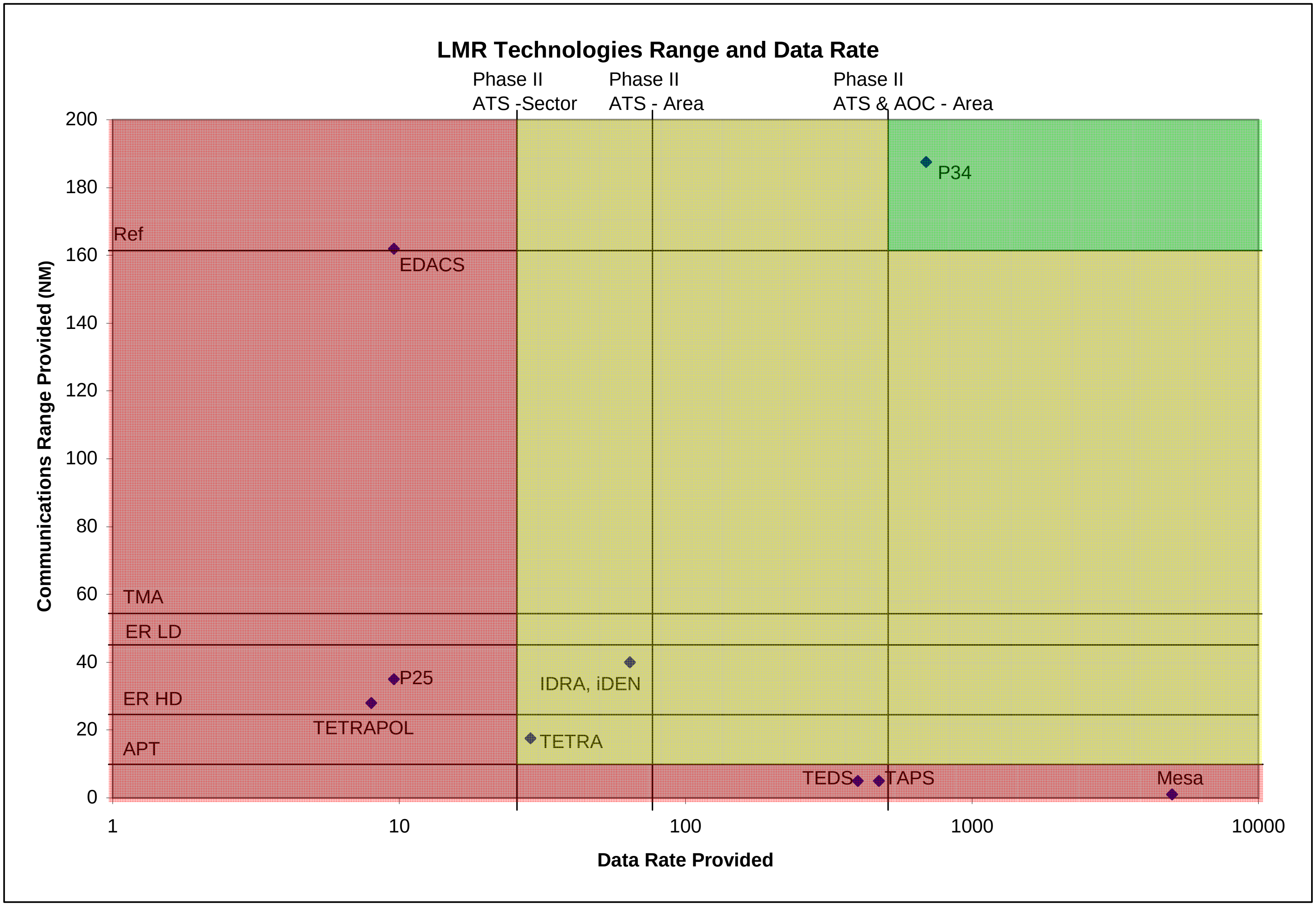
- Show how the technology can provision the required functions by developing the concept of use
- Validate that the technology can provision the required performance by:
  - Define the service volume (based on technology maximum range, or other consideration)
    - Note that smaller service volumes drive cost
  - Use message arrival rates and size distributions from COCR performance modeling group
    - Add in sub-network overhead (COCR loading figures don't account for this)
  - Predict PIAC in service volume using MITRE MLM model outputs
    - Alternatively, use service densities defined in COCR
  - Use M/G/1 queuing model to develop required data rate
- Evaluate against institutional criteria, using methodology of initial screening

Example Application

Example Application of Criteria Subset to Public Safety Technology Family

Technology	Data Rate (kbps)	Range (km)
APCO P25 Phase 1	9.6	35
APCO P25 Phase 2	4.8 ?	TBD
TETRA Release 1	28.8	17.5
TETRAPOL	8	28
IDRA	64	40
iDEN™	64	40
EDACS	9.6	Power Limited
APCO P34	76.8 – 691.2	187.5
Tetra Release 2 – TAPS	Up to 473	5
Tetra Release 2 - TEDS	Up to 400	5
Project MESA	TBD (Large)	TBD (Small)

Comparison by Key Performance Parameters



Summary of Application of Key Performance Requirements

- TAPS, TEDS and Project MESA will meet (most) data rate requirements (especially for ATS only implementations)
  - **However –** they appear to provide insufficient range for even Airport Domain applications

- TETRA, iDEN^{TM}, and IDRA could be solutions in some domains for Phase I requirements only

- P34 is clearly the best representative of the Public Safety and Specialized Mobile Radio family
  - Select P34 for detailed evaluation

Preliminary Results – Key Performance Requirements Filter

Technology Family	General Solution	Airport Surface Solution	ORP Solution
Cellular	WCDMA	WCDMA, CDMA 2000 1xEV, GSM/GPRS/EDGE, TD-CDMA, TD-SCDMA	N/A
IEEE 802	N/A	802.16e, 802.20	N/A
PSR	P34	P34	N/A
Satellite & OTH	INMARSAT, Special Use Satellite Sys.	INMARSAT, Special Use Satellite Sys.	INMARSAT, Special Use Satellite Sys.
Custom VHF	VDL M3T	VDL M3T	N/A
Custom Broadband	E-TDMA, LDL, B-VHF, UAT	E-TDMA, LDL, B-VHF, UAT	N/A
Military	LINK-16	LINK-16	N/A
Other	None	None	N/A

Note: These are not technology recommendations, rather they are the suggested “best of breed” from each technology family. Development of concept of use and evaluation against all requirements is required before recommendations can be made.

Concluding Remarks

Concluding Remarks

- A proposed process is presented that
  - Provides clear insight into why certain technologies are selected for analysis
  - Is objective

- Preliminary results indicate that the recommended technologies from the initial prescreening and the recommended technologies from this second screening will have significant overlap

  - CAUTION – Work is still in progress

  - CAUTION – Detailed evaluations have yet to be completed

Appendix

Derived Evaluation Criteria

Derived Technical Evaluation Criteria

- Process for deriving the following criteria has been presented in an earlier briefing. As a review, the suggested criteria are:
  - Functional Criteria
    - Meets **ATC Data** Needs
      - A/G & G/A Addressed in APT, TMA, ENR, ORP & AOA Domains
      - Ground Originated Broadcast in APT, TMA, ENR, ORP & AOA Domains
      - A/A Addressed in APT, TMA & AOA Domains
      - Air Originated Broadcast in APT, TMA, ENR, ORP & AOA Domains
    - Meets **AOC Data** Needs
      - A/G & G/A Addressed in APT, TMA, ENR & ORP Domains
  - Performance Criteria
    - Data Rate
    - Number of Users
    - Quality of Service
    - Latency

Derived Institutional Evaluation Criteria

- Maturity for Aeronautical Environment
  - Technical Readiness Level
  - Standardization Status
  - Certification Issues
- Cost
  - Ground Infrastructure
  - Aircraft
- Safety and Security
  - Spectrum Protection
  - Security – Authentication and Integrity
  - Security – Robustness to Deliberate RF Interference
- Transition
  - Return on partial investment
  - Ease of technical migration (spectral, physical)
  - Ease of operational migration (air and ground users)

Application of Evaluation Criteria – Defining Metrics

Quantification of Value

- When applying criteria, the fundamental question is one of goodness of fit – that is to say, how well does a particular technology meet the needs of aviation?
  - Metrics must be defined for all criteria
  - Metrics are a means for assessing the goodness of fit of a technology to the criteria
  - Specific example – Data rate
    - The COCR provides guidance on required data rate for the future communications system
      - However, the required data rate is a complex function of the number of users in a service volume,
      - COCR provides “point solutions” – values of required data rate for specific service volumes, and per user
      - COCR values must be extended to evaluate a technology in accord with the coverage volume that is predicated by the technology concept of use

Defining the Measures - Required Data Rate

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Table 8-3: Air/Ground Capacity Requirements (kbps) – Phase 1

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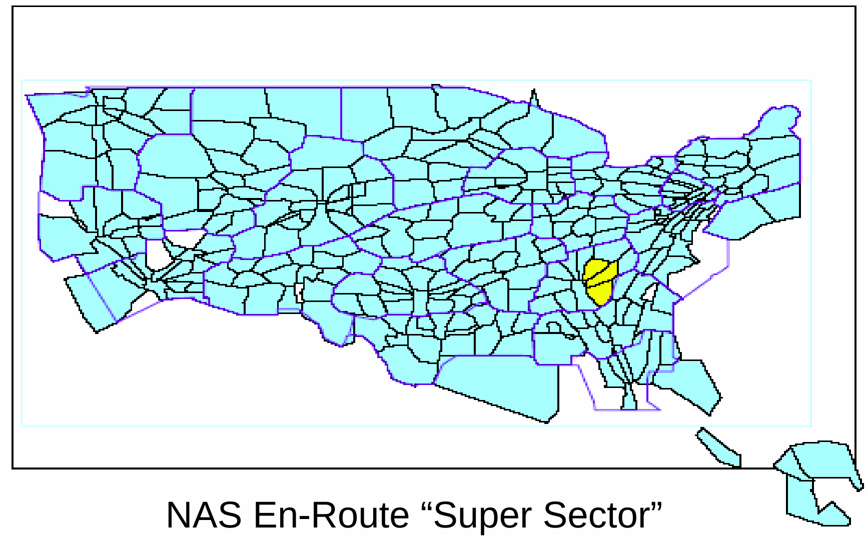

NAS En-Route “Super Sector”

- COCR A/G Capacity requirements shown
  - Required data rates range between 0.3 kbps and 168.9 kbps
  - Maximum is for the NAS 2030 “Super Sector” shown on the map
- COCR also provides “per aircraft” data rates
  - Required rate does not scale as a multiplicative factor

Notes About Required Capacity

- Technologies that can't supply required capacity might still add value
  - In the context of a CAA's particular roadmap, a set of operational services (e.g., auto-execute) might never be implemented
    - Reduction in required data rate
  - Provisioning of ATS and AOC might always remain separate in a given region
    - Reduction in required data rate
  - In accord with the CAA's particular roadmap, other systems (e.g, VDL M2) might be deployed before the FRS
    - The FRS would then be used to supplement the capacity of the (previously) deployed system
    - Reduction in required data rate

Extending COCR Data Rate Requirements

- In general, a technology can be evaluated as
  - "Sector Based" – this is the concept that is detailed in the COCR, with larger future sectors being accounted for, but the volume of coverage is still smaller than technology coverage constraints
  - "Area Based" – in this concept, a regular grid of ground stations is deployed, with minimal overlap of coverage (except for required redundancy for availability concerns)
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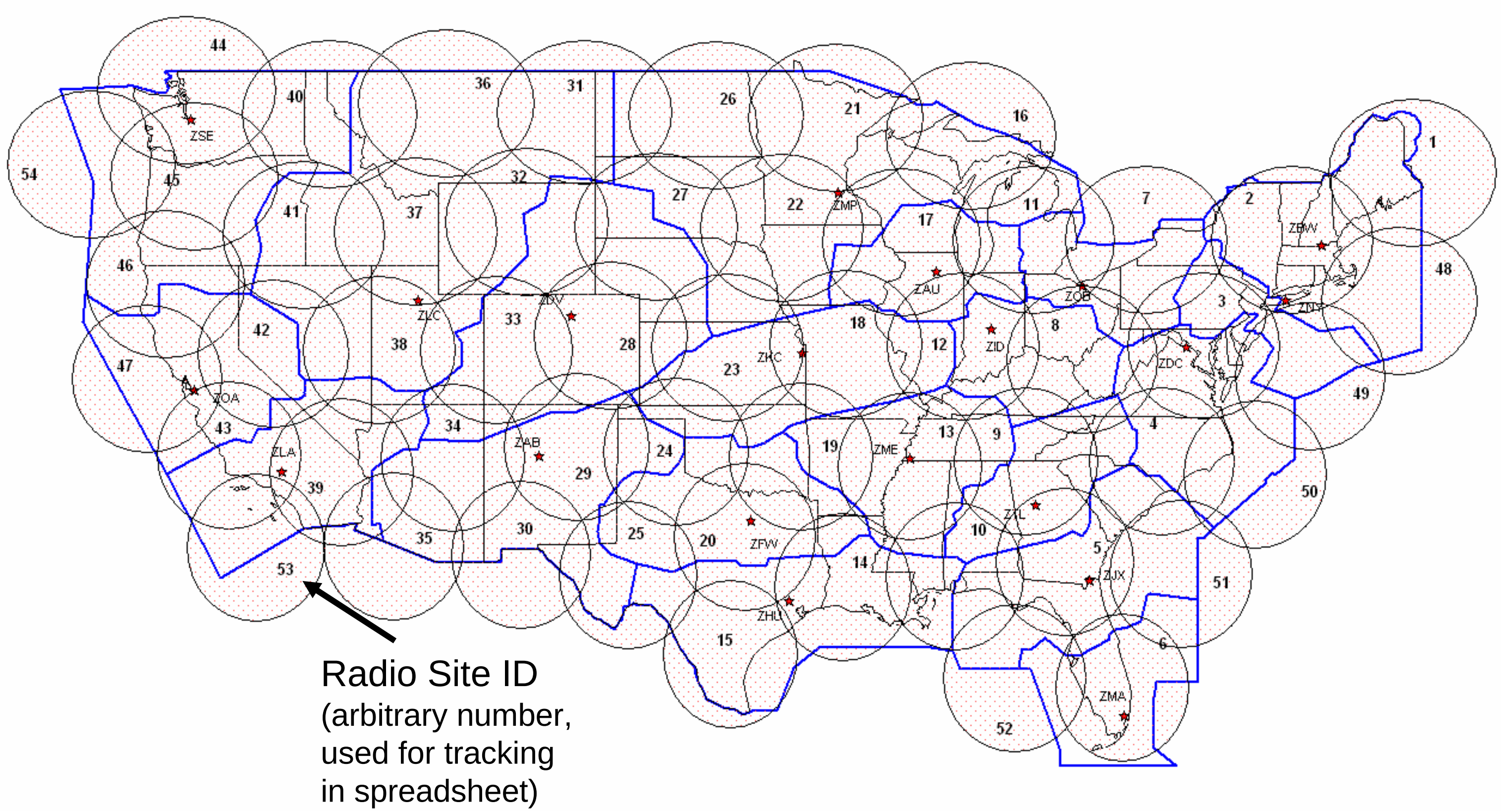
- COCR provides data rate requirements for specific service volume size (sector based) and for individual users
  - COCR provides a sound engineering process for deriving the required capacity for any arbitrary volume (area based)

Developing Data Requirements for an Example Architecture

- A process was defined to develop the data requirements for an example architecture that builds upon the work of the COCR performance requirements sub-group
  - Develop a link-budget required to provide coverage to the radio horizon for the flight level above which coverage is required
  - Develop a notional regular grid for technology deployment
    - This radio layout is selected to provide 100% coverage to service volume of interest
  - Predict aircraft traffic in each service volume
    - Used MITRE MLM model to predict traffic in the study timeframe
    - An alternative process would be to use the COCR aircraft density numbers (Table 7.6)
  - Accounting for sub-network overhead, predict required server capacity in each service volume
    - Use the same methodology as COCR performance requirements sub-group
      - M/G/1 queue with same arrival rates and message sizes
    - Server capacity and air-interface data rate are tightly coupled

Developing Data Requirements for an Example Architecture (2)

- Reference architecture provides coverage above FL180
  - Coverage volumes predicated on link budget which includes 4 dB excess path loss (average prediction of Johnson-Gierhart rolling plains)
- Graphic shows regular grid selected for reference architecture



Developing Data Requirements for an Example Architecture (3)

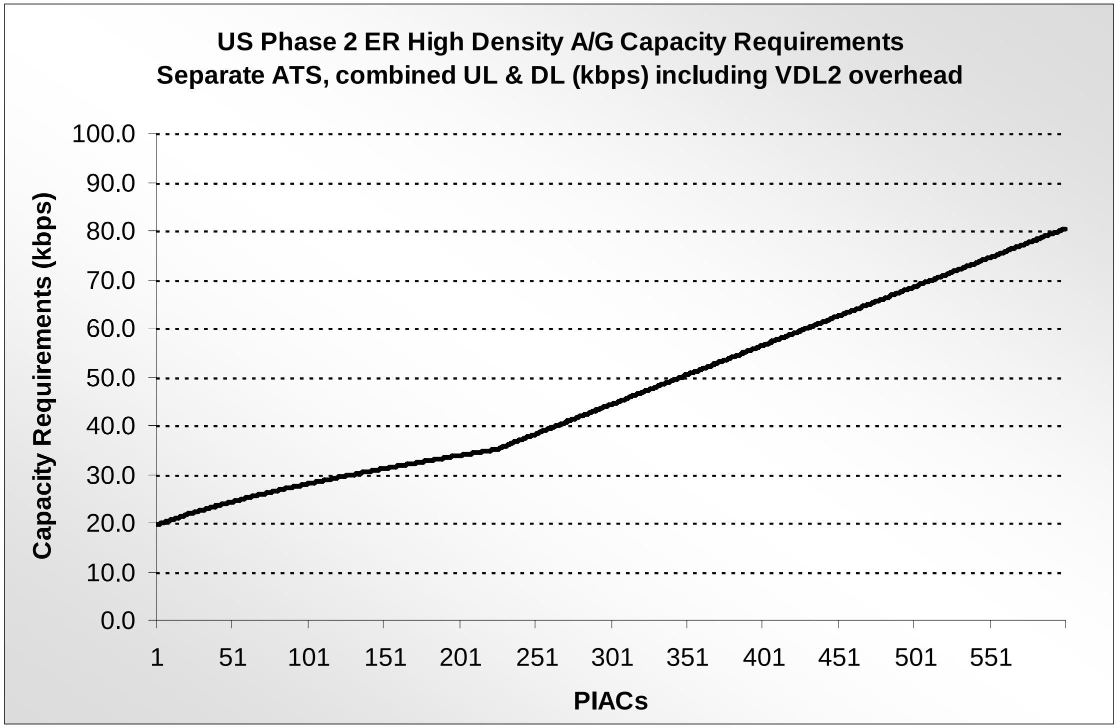
- An estimate of the Peak Instantaneous Aircraft Count (PIAC) in each radio coverage volume was developed
- To formulate this estimate,
  - Used 2020 PIAC number from MITRE MLM data
    - This provides a projected number of aircraft in the en-route sectors of each center (ARTCC)
  - Assume uniform distribution within ARTCC
  - Derive PIACs for each ARTCC above Flight Level 180
    - This step is necessary as the radio coverage area (assumed) was for flight level 180 and above, and the MITRE data sometimes includes aircraft below this flight level
  - For each radio site estimate % ARTCC(s) coverage
    - This step allows an estimate of the percent of aircraft in each center that fall in a particular radio site's coverage volume
  - Calculate PIACs for each radio site

Developing Data Requirements for an Example Architecture (4)

- Use COCR loading analysis to derive capacity requirements
  - COCR analysis includes message overheads through the Network layer (assumes ATN OSI overheads), models arrival rates for each message type and treats the A/G network as an M/G/1 server
- Add VDL-2 message overhead to account for sub-network loading[1]

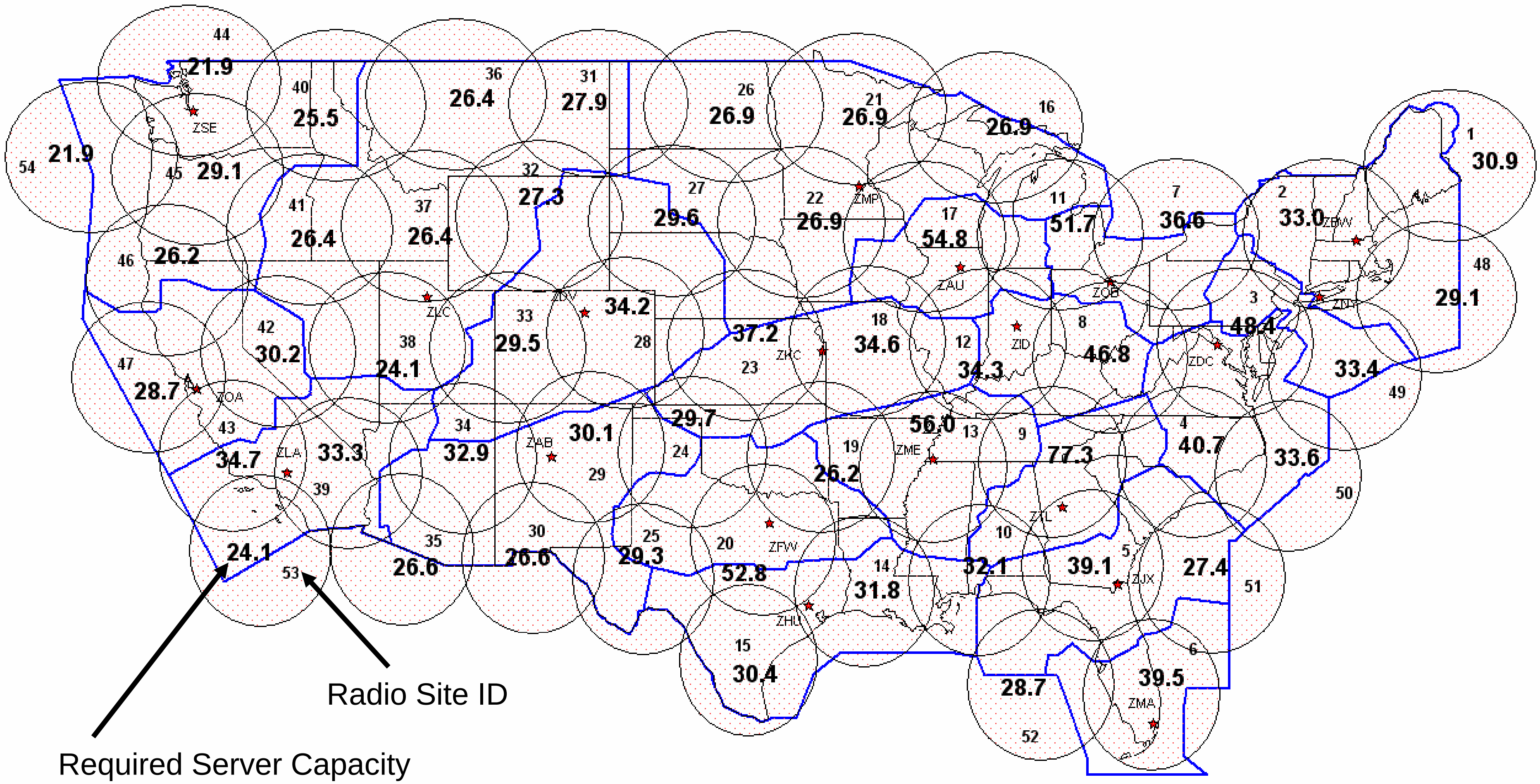
[1]Loading is not particularly sensitive to the sub-network overhead. For example, inspection of the graph to the right does not show appreciable differences between the fully loaded message set and the COCR loading analysis, which leaves off at the network point of attachment.

This is not the case for channel access mechanism, which can significant impact the required data rate.



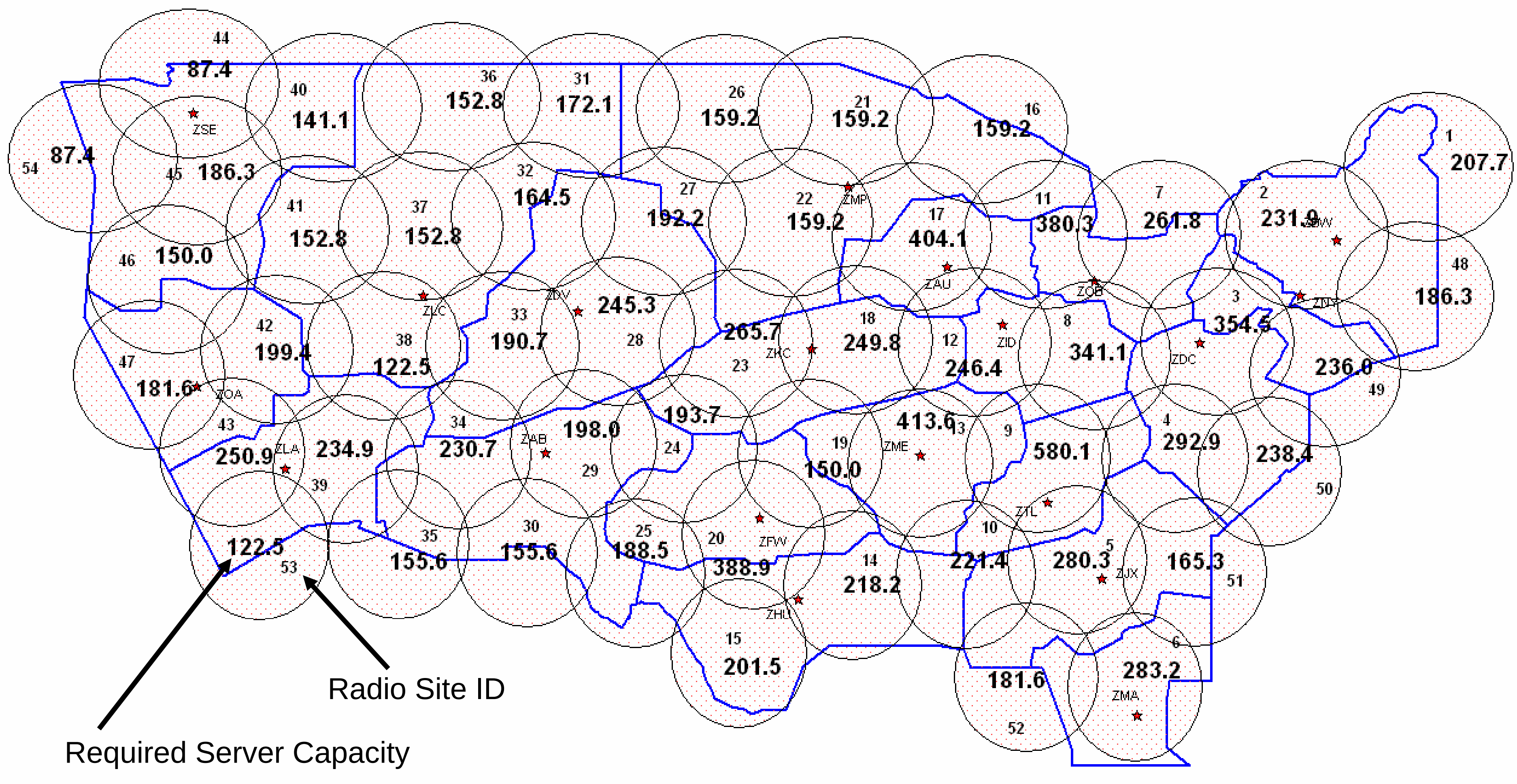
Developing Data Requirements for an Example Architecture (5)

- The graphic shows the derived server capacity of each ground radio site for *ATS traffic only*
  - Required server capacity range is 21 – 77 kbps



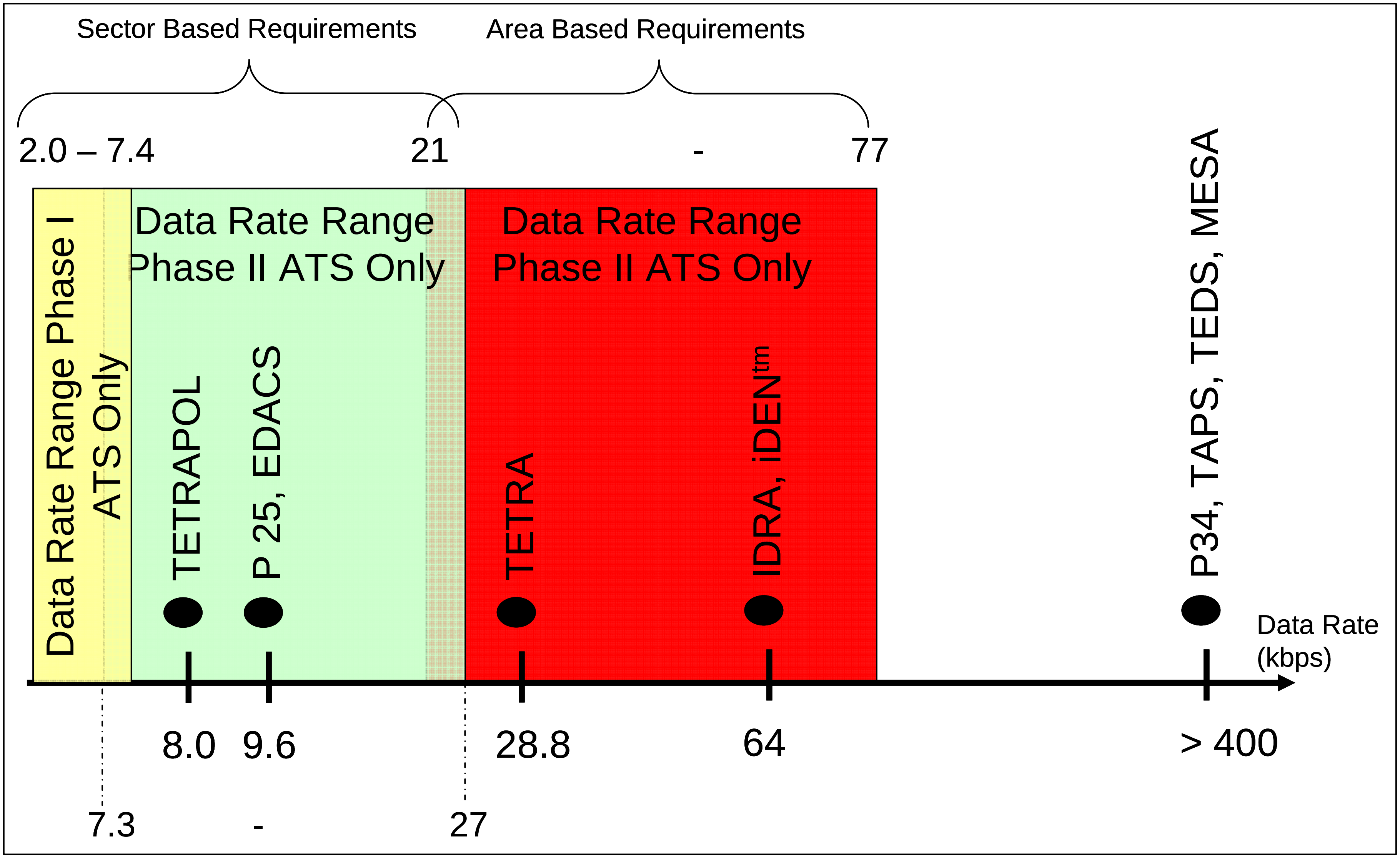
Developing Data Requirements for the Reference Architecture (6)

- The graphic shows the derived server capacity of each ground radio site for *ATS & AOC traffic*
  - Required server capacity range is 87 – 580 kbps

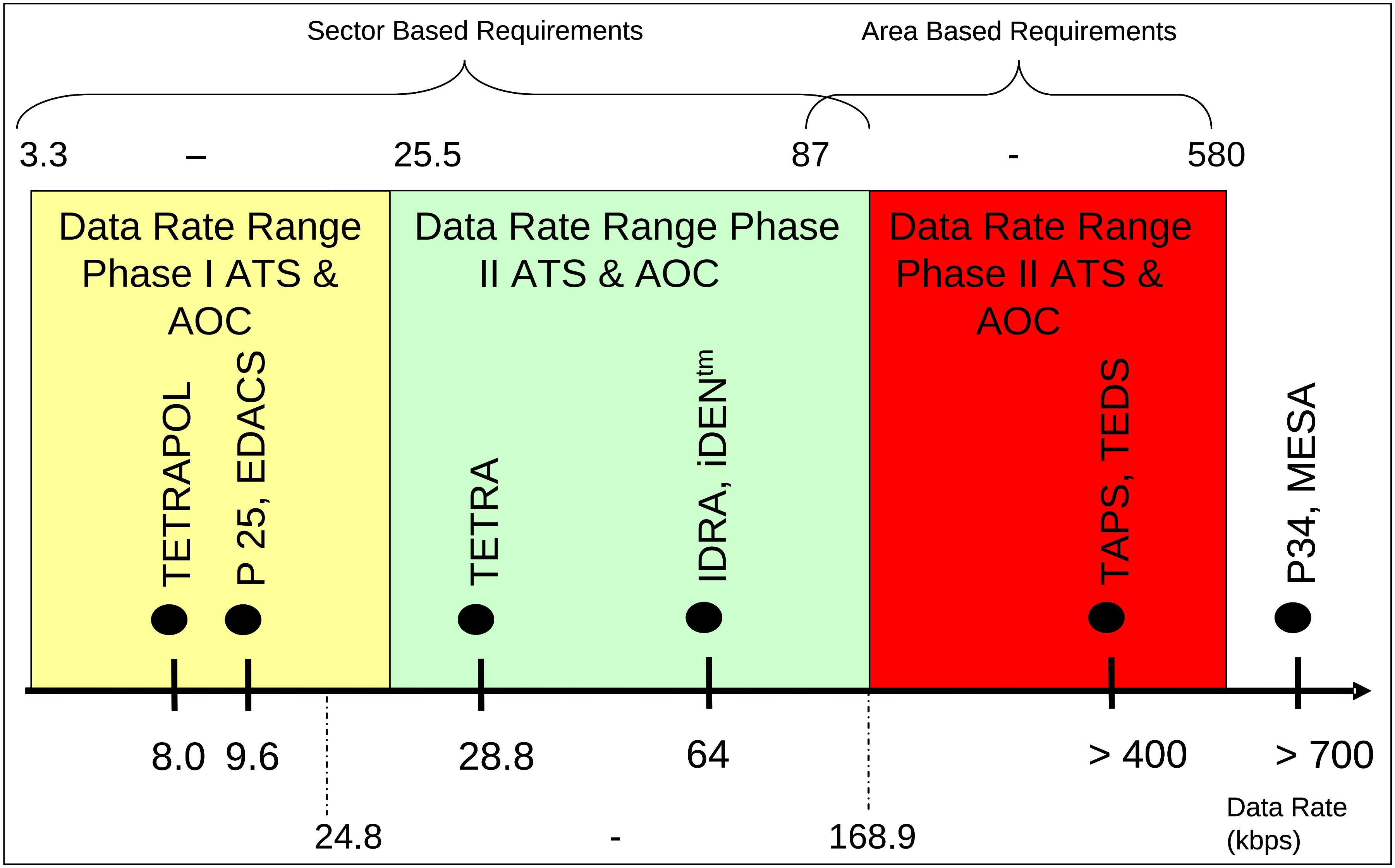


Example Application

Comparison of Requirements (ATS Only) and LMR Data Rates Provided



Comparison of Requirements (ATS & AOC) and LMR Data Rates Provided



Observations

- ATS Only Data Link Systems
  - Sector Based
    - For Phase I, all of the LMR candidate technologies have sufficient capacity
    - For Phase II
      - TETRAPOL, P25 and EDACS do not have sufficient capacity
      - TETRA (Phase I), IDRA, iDEN^{tm}, P34, TAPS, TEDS and MESA all have sufficient capacity
  - Area Based
    - For Phase II only P34, TAPS, TEDS and MESA have sufficient capacity
- ATS & AOC Data Link Systems
  - Sector Based
    - For Phase I, P25, EDACS and TETRAPOL do not have sufficient capacity
    - For Phase II only P34, TAPS, TEDS and MESA have sufficient capacity
  - Area Based
    - For Phase II only P34 and MESA have sufficient capacity